Campsite Area Monitoring in the Colorado River Ecosystem: 1998 to 2003

Final Report

By:

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Executive Summary

River runners and hikers use sand bars deposited along the Colorado River below Glen Canyon Dam as campsites. Because of their crucial role to the river recreational experience, the relative size, distribution, and quality of campsites within the Colorado River Ecosystem (CRE) are of concern to river. This monitoring study was designed to determine whether or not a management objective for the recreational resources outlined in the Glen Canyon Dam Adaptive Management Program (GCDAMP) strategic plan was being met. We accomplished this by annually surveying the campsite area at a number of representative sites throughout the CRE between Lees Ferry and Diamond Creek.

This report presents the results of six years of campsite area monitoring. We use a total station survey-based technique to measure campsite area at thirty-one long-term monitoring sites (Kaplinski et al., 1995; Hazel et al., 1999) (Figure 1). Our method for determining area is similar to the methods of Kearsley and Warren (1993), Kearsley et al. (1994), Kearsley (1995), and Kearsley and Quartaroli (1997), but improves on measurement precision. We also incorporate empirically derived stage-discharge relationships for each site that allows an analysis of campsite area changes within specific ranges of discharge.

Our results show that operations from Glen Canyon Dam are not meeting the management objective of the GCDAMP with respect to the size, quality, and distribution of camping beaches within the CRE. In six years, more than half of the available campsite area at the study sites has been lost. From 1998 to 2003, camping area above the 25,000 ft ^{3}/s stage elevation has decreased by 55%. The average rate of change was 15% per year. The decrease in high elevation campsite area has occurred in Marble Canyon and Grand Canyon (above and below the Little Colorado River) as well as within critical and non-critical reaches. Only lower elevation campsite areas have increased since 2000 and the total campsite area below the 25,000 ft^3/s stage elevation now exceeds the area available at higher elevations.

The continued existence of sand bars suitable for camping in this system depends on high flows to redeposit sediment lost through the natural processes of erosion and to scour or remove vegetation. Therefore, the availability of campsite area is closely linked with the frequency of flood events from GCD. Unless vegetation is physically removed,

high flow events are the only mechanism by which sand bars used as campsites above the 25,000 ft^3/s stage elevation can be built and maintained – provided that enough sediment is available for deposition.

Research and monitoring of the recreational resources within the CRE suffers from a lack of coordination and integration. This study, for example, directly addressed only one of the five management objectives for the GCDAMP with respect to their stated goal of maintaining or improving the quality of the recreational experience within the CRE. Four of the five management objectives designed to assess whether or not this goal is being achieved are not currently being addressed. In addition, the National Park Service (NPS) has responsibilities to monitor the recreational use within the CRE. In order to include the full suite of management objectives of both the GCDAMP and NPS, a cooperative and integrated program of recreational monitoring and research should be developed. In addition to campsite area monitoring, future research and monitoring should be integrated to include inventories of the total number of campsites, synthesize and collate existing information to construct a comprehensive view of post-dam changes, evaluate the carrying capacity of the river corridor, as well as psychological (experiential) aspects of the resource. These studies would compliment the detailed area measurements and provide resource managers a more complete assessment of the effects of dam operations on the environmental and social values for which Grand Canyon National Park was formed.

Acknowledgements

This project was supported through a cooperative agreement between Northern Arizona University and the Grand Canyon Monitoring and Research Center as part of the Glen Canyon Dam Adaptive Management Program. Thanks to Ruth Lambert for initiating this project and to Helen Fairley for helpful discussions and making sure it was completed, Carol Fritzinger for her logistical wizardry, Jeff Behan for his relishes, assistance and many conversations, and to all the Nams and boatmen who participated in the field surveys.

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Introduction

River runners and hikers use sand bars deposited along the Colorado River below Glen Canyon Dam (hereafter referred to as the Colorado River ecosystem, or CRE) as campsites (Figure 1). Because of their crucial role to the river recreational experience, the relative size, distribution, and quality of campsites within the CRE are of concern to river managers (U.S. Department of Interior, 1995; GCDAMP Strategic Plan, 2001). This monitoring study was designed to determine whether or not the goals and management objectives for the recreational resources outlined in the Glen Canyon Dam Adaptive Management Program (GCDAMP) strategic plan are being met (GCDAMP Strategic Plan, 2001). We accomplished this by annually surveying the campsite area at a representative number of sites throughout the CRE between Lees Ferry and Diamond Creek (Figure 1).

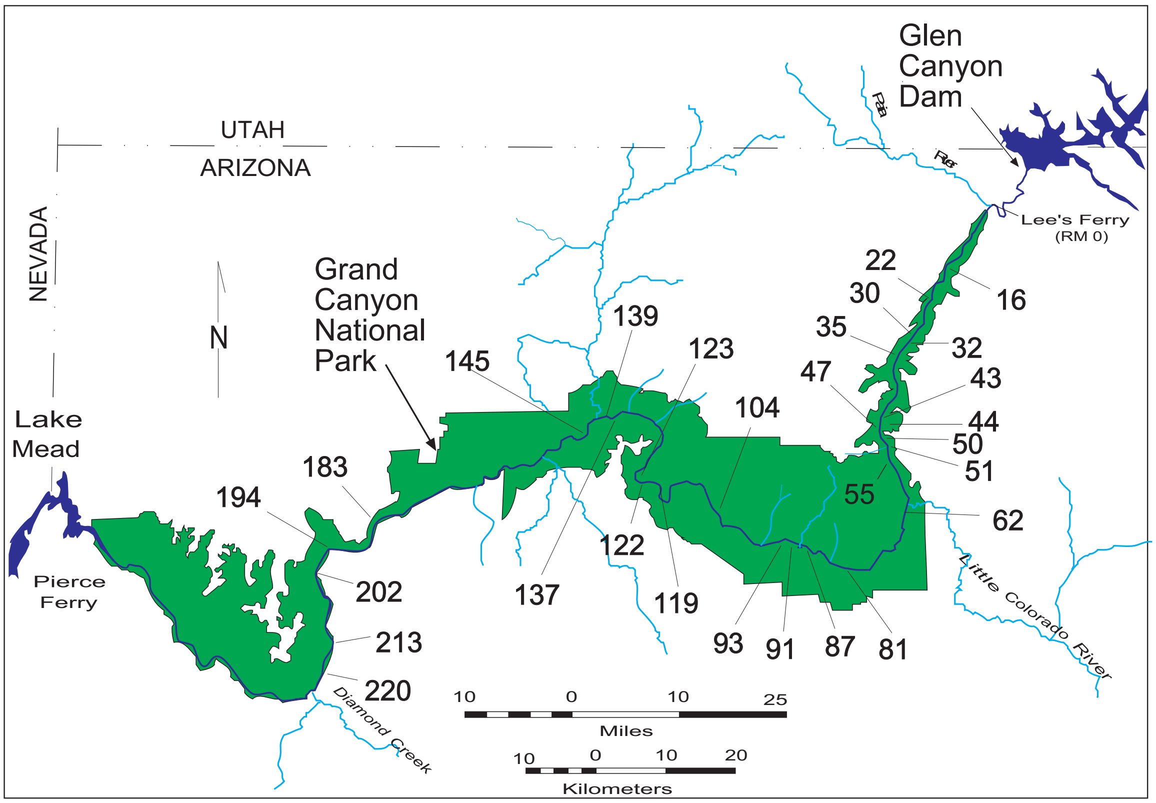


Figure 1. Map of study area showing the location of study sites. Shaded area is Grand Canyon National Park. Study site location is noted by river mileage.

This report presents the results of six years of campsite area monitoring. We use a total station survey-based technique to measure campsite area at thirty-one long-term monitoring sites (Kaplinski et al., 1995; Hazel et al., 1999) (Figure 1). Our method for determining area is similar to the methods of Kearsley and Warren (1993), Kearsley et al. (1994), Kearsley (1995), and Kearsley and Quartaroli (1997), but improves on measurement precision. We also incorporate empirically derived stage-discharge relationships for each site that allows an analysis of campsite area changes within specific ranges of discharge.

Previous Work

Previous monitoring studies of campsite area were conducted by Weeden et al. (1975), Brian and Thomas (1984), Kearsley and Warren (1993), Kearsley et al. (1994), Kearsley (1995), Kearsley and Quartoroli (1997). These studies evolved from qualitative estimates of campsite carrying capacity to quantitative aerial photographic measurements. Weeden et al. (1975) and Brian and Thomas (1984) focused on developing an inventory of the size and number of campsites throughout the river corridor. Both of these studies estimated the capacity of each site above the 24,000 to 28,000 ft^3/s stage elevation, where capacity is defined as the number of campers that can occupy a campsite for an overnight stay. Kearsley and Warren (1993) repeated the inventory and improved the campsite area measurements by developing techniques to quantitatively measure campsite area from aerial photography and videography. Kearsley and Warren (1993) also divided campsites between Lees Ferry and Diamond Creek into critical and non-critical reaches. A critical reach was defined as any contiguous stretch of the river in which the number of available campsites is limited due to geological characteristics, high demand due to attraction sites, or other logistical factors. Non-critical reaches were defined as any stretch of the river in which campsites are plentiful and little competition for the majority of sites occur. These reach definitions closely parallel the geomorphic reach definitions of Schmidt and Graf (1990).

Subsequent studies by Kearsley et al. (1994), Kearsley (1995), and Kearsley and Quartoroli (1997) improved upon the aerial photographic mapping by utilizing Geographic Information System (GIS) software. Their technique involved outlining camp area during on-site visits onto 400% Xerox copies of 1:4800 aerial photographs, then digitizing the polygons and calculating areas in a GIS environment. Ticks marks for registering the photographs were either taken from common points identified on base maps (Werth et al., 1993), or using a conversion factor between digitizer units and actual ground distances. This conversion factor, derived by measuring the distance between recognizable features on the aerial photograph during the on-site visit and dividing by the digitizer units between the same features, was used to convert digitizer units to square meters. This technique is subject to error from estimates of stage elevation, digitizing (registration, polygon digitizing, distortion of copies of aerial photography), and from using the conversion factor to derive area.

Kaplinski et al. (2003) conducted a review of the different methodologies used to monitor campsite area and campsite inventories. They concluded that the total station mapping methods (used in this study) and mapping utilizing digital orthophotography (collected by GCMRC in May 2002) both provided the appropriate level of accuracy and precision necessary for quantifying campsite area changes. The analysis also showed that the methods utilized by Kearsley and Warrren (1993) also provide a good estimate of camp area and results from historical aerial photo analysis can be compared to current and future measurements with a reasonable level of confidence.

Objectives

The objectives of this study were focused on describing changes in the size of camping areas in the CRE (Figure 1). The objectives of this study were:

1. Annually measure campsite area at the long-term monitoring sites.
2. Evaluate the change in campsite area between each year and between different ranges of flow.

These objectives specifically target management objective 9.3 of the GCDAMP (GCDAMP strategic plan, 2001).

Methods

Surveys were conducted in October in 1998, 1999, 2000, 2001, 2002, and 2003 to quantify campsite area change. Surveys at the selected study sites were conducted using standard total station survey techniques (USACOE, 1994). Survey crews consisted of an instrument operator, one to two rodmen and a crew chief. At each site, a rodman was directed to points that outline the perimeter of camping areas, as well as points that outline the perimeter of exclusions to the camp, such as trees and rocks (Figure 2a). At each point, the instrument operator places the crosshairs of the optical 10X scope on the center of the reflective prism held by the rodman and records the coordinates (x,y,z) of the point. The points are subsequently used to define polygons of campsite area. We adopted the criteria of Kearsley (1995) and Kearsley and Quartoroli (1997) to identify campable area. Campable area is defined as a smooth substrate (most likely sand) with no more than eight degrees of slope with little or no vegetation. Slope angle was determined visually by the crew chief. From 1998 to 2000, the crew chief also mapped the areas onto 400% enlargements of the most recently acquired aerial photographs. These sketch maps were used on return visits to enable duplication of the camp area and by Kaplinski et al. (2003) to conduct a comparison of the two methods. Not all camp areas were mapped at every site. Instead, representative camp spots were selected across a range of stage elevations. Camping areas not represented in the mapping were typically far (>100 m) from the main mooring/cooking areas.

Survey points for each site were downloaded from field data collectors and checked for proper control coordinates and elevation. Digital elevation models (DEMs) were formed within the area boundaries using a survey-grade software package (Sokkia MapVista). The elevations of the various stage elevations were derived from an empirically derived stage discharge relationship at each site (Figure 2b). We measured camp area above the 20,000 ft^3/s stage elevation on all trips and lower elevation camp areas when lower flow releases allowed. To examine camp area changes within different flow ranges, we divided camp area into six categories (Figure 2c). These categories reflect different stage elevations reached by previous and proposed GCD operations. The plan area within different ranges of stage elevation was calculated from the DEMs and tabulated in a spreadsheet (Table 1, Appendix A).

A)

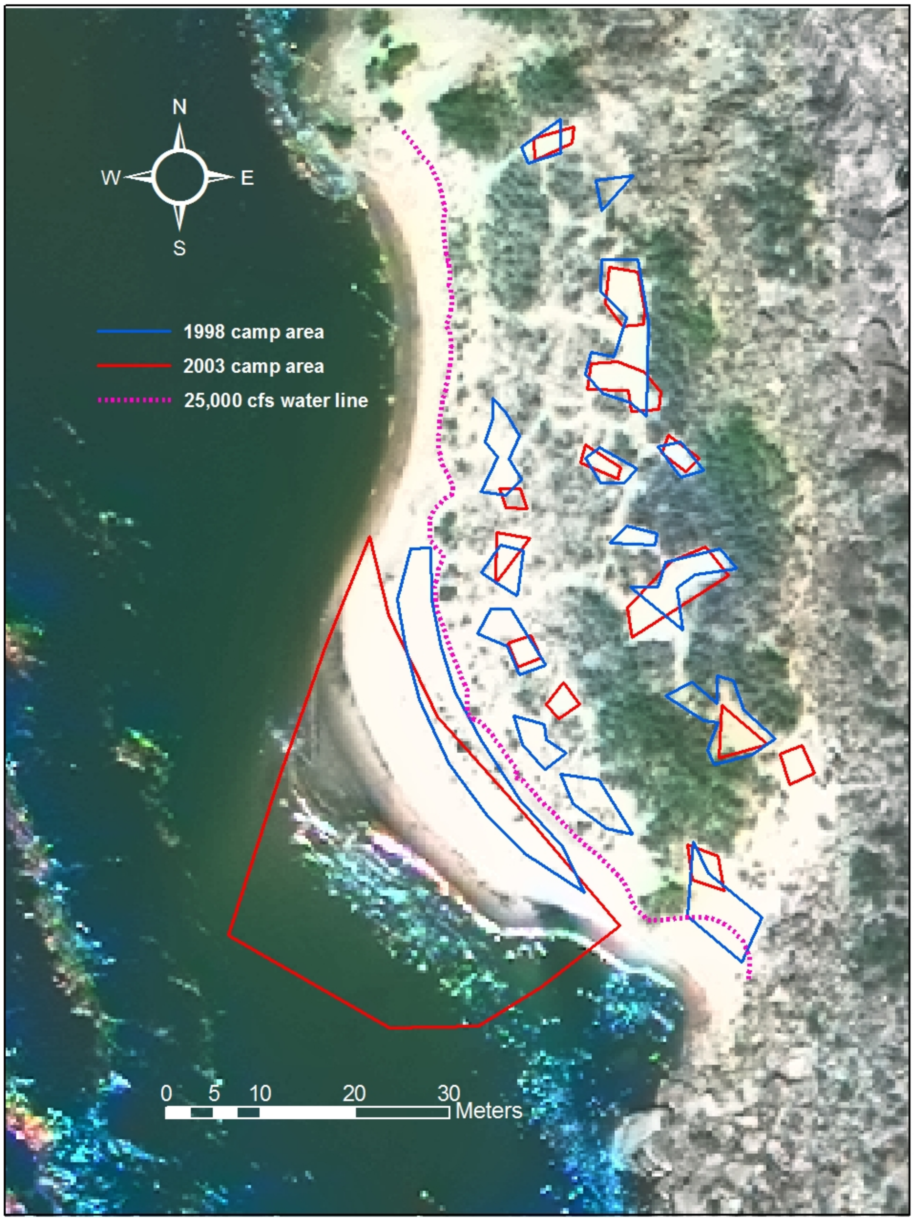
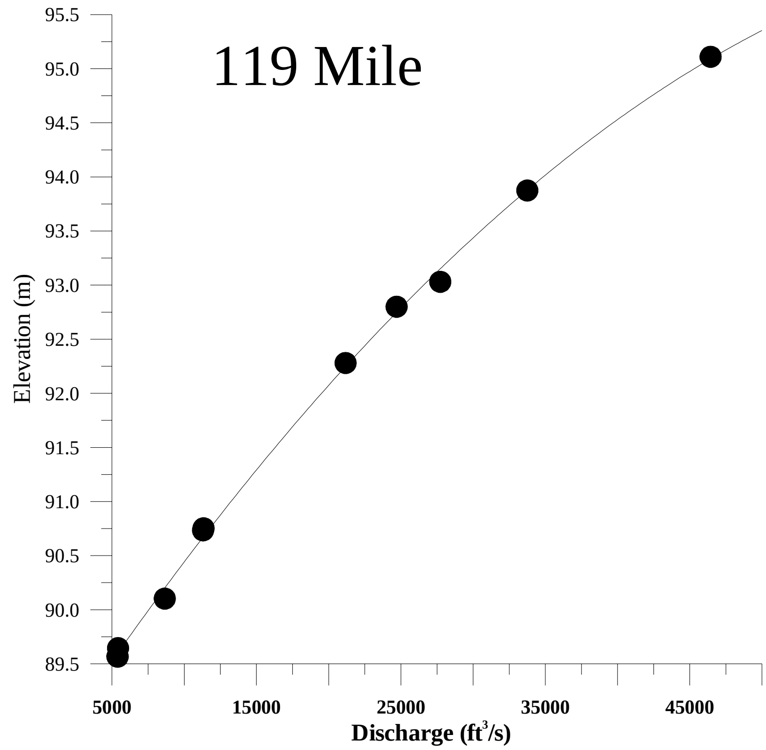


Figure 2. Examples from the 119 Mile study site of the types of data used in this study. A) Map of the 119 Mile site showing campsite area polygons from 1998 (blue), 2003 (red), and the 25,000 ft^3/s stage elevation line (purple) overlain on the May 2002 Orthophoto. B) Stage discharge relationship. C) Campsite area divided into specific stage ranges. Note the large increase in camp area within the 20,000 to 25,000 ft^3/s and 25,000 to 30,000 ft^3/s stage ranges from 1999 to 2000. Two high flow events (31,000 ft^3/s) in the spring and fall of 2000 aggraded the lower portion of the reattachment bar, thus increasing the area available for camping. Note also that the orthophoto was collected in 2002 and does not reflect the configuration of the lower elevations of the sand bar at the time of the camp area mapping.

B)


119 Mile
Elevation (m)
95.5
95.0
94.5
94.0
93.5
93.0
92.5
92.0
91.5
91.0
90.5
90.0
89.5
5000
15000
25000
35000
45000
Discharge (ft^3/s)

C)

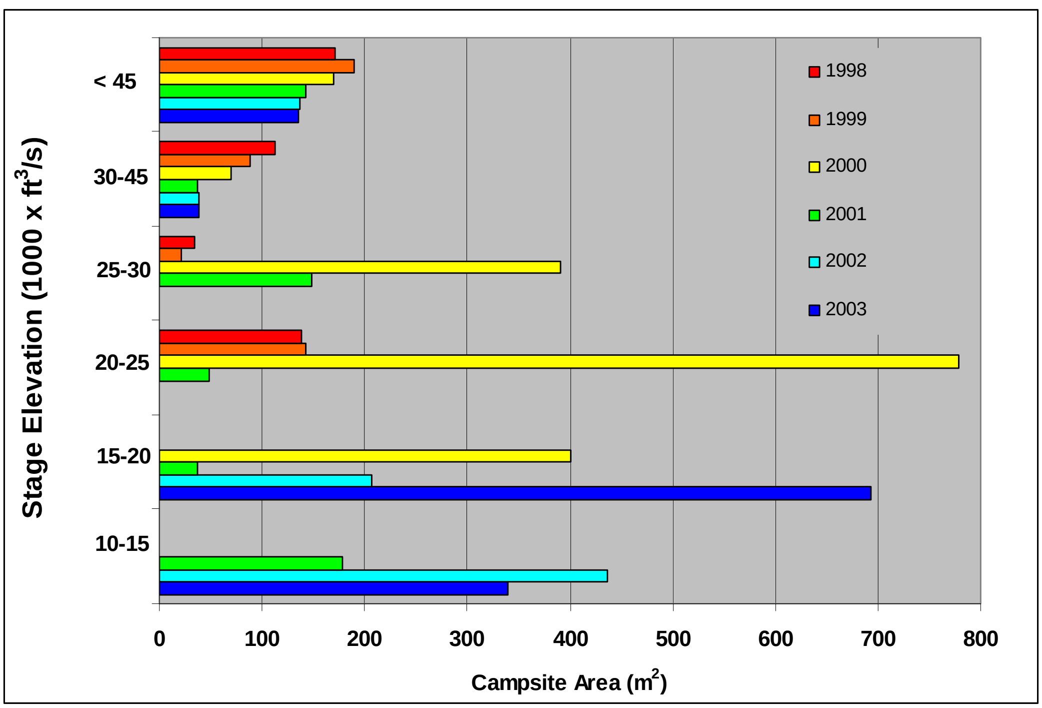

Stage Elevation (1000 x ft^3/s)
< 45
30-45
25-30
20-25
15-20
10-15
1998
1999
2000
2001
2002
2003
0
100
200
300
400
500
600
700
800
Campsite Area (m^2)

Fig 2. cont.

We investigated the precision of the method at one site (River Mile 35.0, Nautoloid, Table 1, Appendix A) by mapping camp area with two separate crews on the same day. The difference in area between these two surveys was less than 3%. However, a certain level of subjectivity is inherent in choosing boundaries for the areas to be mapped – even while following the criteria outlined above. Subjective decisions are made at each site while identifying and choosing the areas to be mapped. Therefore, we use a more conservative estimate of change detection and consider changes of 10% or greater to be significant.

Dam releases during the study period

Dam releases during the study period included normal operations guided by the 1996 Record of Decision (ROD, U.S. Department of Interior, 1996) from 1998 to 2003, a Low Steady Summer Flow (LSSF) experiment during 2000, and experimental high fluctuating flow experiments from January to March in 2002 and 2003 (Figure 3). Normal dam releases fluctuate diurnally and seasonally, based on power demand and water delivery schedules. Typically, flow releases are higher in the winter and summer months, and lower during the spring and fall months. In 1998 and 1999, daily mean flow releases ranged from an average of approximately 19,400 ft^3/s in high-volume months to approximately 12,400 ft^3/s in low-volume months. The Low Steady Summer Flow (LSSF) experiment in 2000 consisted of two high flow releases in the spring and fall, and a period of low steady (no diurnal fluctuation) flow during the summer. The low steady flow during the summer was lowered to a constant 8,000 ft^3/s. The high flows were short-duration, 4 day, releases of 31,000 ft^3/s. These were the only two flows large enough to reach above the 25,000 ft^3/s stage elevation during the study period.

Flow levels during the 1998 and 1999 survey trips were fluctuating from 10,000 to 18,000 ft^3/s. Therefore, we were only able to measure camp areas consistently at every site above the 15,000 ft^3/s stage elevation. Subsequent analysis of campsite area below 25,000 ft^3/s excludes the measurements made during 1998 and 1999. During the 2000 to 2003 surveys, low volume releases allowed measurement of camp area above the 10,000 ft^3/s stage elevations at some sites and above 15,000 ft^3/s at all sites. High fluctuating flow experiments were conducted from January through March in 2002 and 2003.

During these experiments the flows fluctuated from 5,000 to 20,000 ft^3/s. Comparison of camp area change between surveys was conducted using area measured above the 25,000 ft^3/s stage elevation, the maximum stage of fluctuating flows under ROD operating criteria.

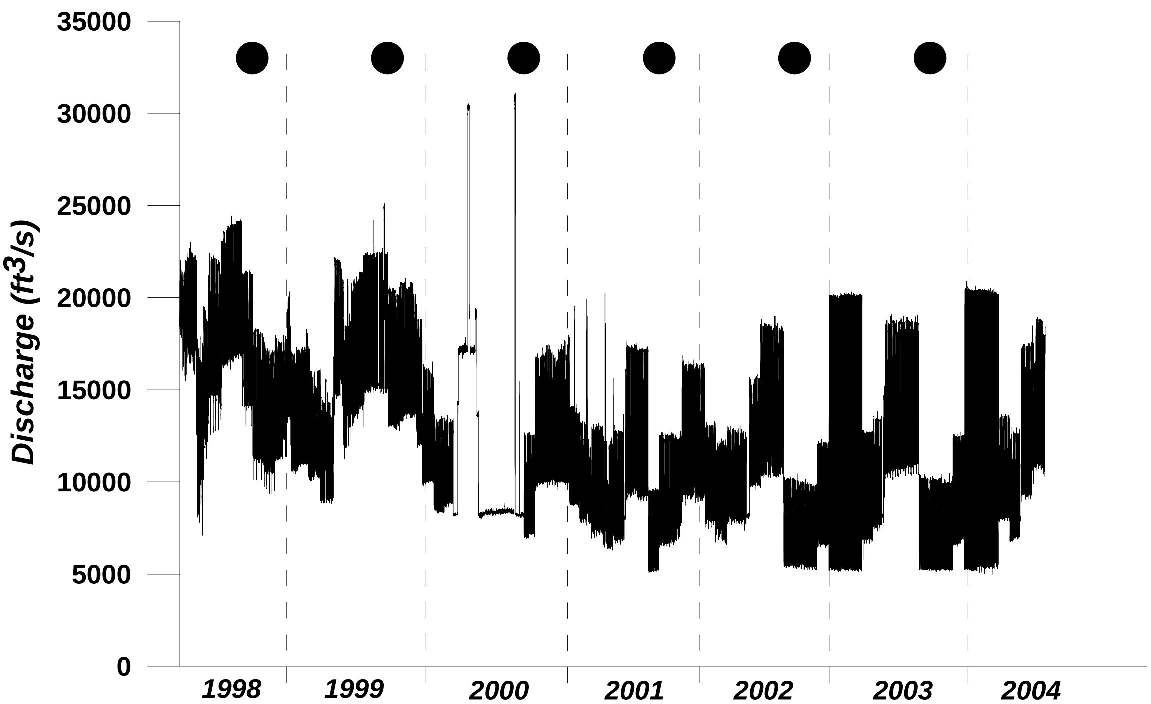


Figure 3. Daily mean discharge hydrograph from USGS gaging station Colorado River near Lees Ferry (09380000) during period of study. Note the daily and seasonal fluctuations in flow volume during 1998 and 1999, and the Low Steady Summer Flow (LSSF) experiment in 2000 that included two high flow events.

Table 1. Study site location, area and percent change between surveys.

Mile	side	name	reach	1998 area	1999 area	2000 area	2001 area	2002 area	2003 area	1998-1999 % change	1999-2000 % change	2000-2001 % change	2001-2002 % change	2002-2003 % change
16.6	l	upper hot na na	C	367	362	395	68	77	89	-1	9	-83	13	15
16.6	l	lower hot na na	C	117	133	180	76	65	76	14	35	-58	-14	17
22.1	r	22 mile	C	66	43	152	146.6	106	74	-35	253	-4	-28	-30
23.5	l	24 mile - H. McD's camp	C					4	0					-100
29.5	l	silver grotto	C					183	177					-3
30.7	r	fence fault springs	C	297	352	99	74	35	28	19	-72	-26	-52	-20
31.9	r	south canyon	C	642	675	618	572	315	487	5	-8	-7	-45	55
35.0	l	nautoloid	C	464	542	498	470	442	446	17	-8	-6	-6	1
41.2	r	buck farm	NC					528	483					-9
43.4	l	anasazi bridge	NC	1105	1014	933	526	505	126	-8	-8	-44	-4	-75
44.5	l	eminence	NC	599	626	534	453	512	567	5	-15	-15	13	11
45.0	l	Willie Taylor	NC					184	84					-54
47.6	r	lower saddle	NC	765	807		272	199	368	5			-27	85
50.1	r	dino	NC	703	786	678	726	766	472	12	-14	7	6	-38
51.5	l	51 mile	NC	1277	653	552	270	420	221	-49	-15	-51	56	-47
55.9	r	kwagunt marsh	NC	548	424	273	195	126	30	-23	-36	-29	-35	-76
62.9	r	Crash	NC	180	172	185	82	46	26	-4	8	-56	-44	-43
81.7	l	grapevine	C	1166	1128	1136	1097	852	531	-3	1	-3	-22	-38
84.6	r	Clear Creek	C			97		29	19					
87.7	l	upper cremation	C	200	204	169	117	175	147	2	-17	-31	50	-16
87.7	l	lower cremation	C	315	193	236	145	134	92	-39	22	-39	-8	-31
91.7	r	91 mile - above trinity	C	286	286	301	307	209	271	0	5	2	-32	30
93.8	l	granite	C	204	162	352	210	223	143	-21	117	-40	6	-36
104.4	r	104 mile	C	133	98	135	158	138	81	-26	38	17	-13	-41
119.4	r	119 mile	NC	317	300	631	328	177	174	-5	110	-48	-46	-2
122.8	r	122 mile	NC	472	456	289	222	273	373	-3	-37	-23	23	37
123.2	l	forster	NC	376	402	295	224	158	41	7	-27	-24	-29	-74
137.7	l	football field	C	627	573	786	685	838	643	-9	37	-13	22	-23
139.6	r	fishtail	C	323	286	179	61	78	107	-11	-37	-66	28	37
145.9	l	145 mile - above Olo	C	118	114	289	178	152	121	-3	154	-38	-15	-20
167.1	l	lower National	NC					182	162					-11
183.3	r	183 right - old river channel	NC	146	136	179	143	85	65	-7	32	-20	-41	-24
183.3	l	183 left	NC	391	114	199	192	176	150	-71	75	-4	-8	-15
194.6	l	194 mile - Hualapai Acres	NC	1124	817	776	596	723	511	-27	-5	-23	21	-29
202.3	r	202 mile	NC	740	715	526	745	432	383	-3	-26	42	-42	-11
213.3	l	Pumkin Springs	NC	411	216	128	78	51	16	-47	-41	-39	-35	-69
220.1	r	220 mile - middle gorilla	NC	1600	1109	1010	1140	660	428	-31	-9	13	-42	-35
			Mean	519	448	413	341	277	222	-11	17	-24	-11	-19
			Std. Error	69	56	52	53	40	31	4	12	5	5	6

Study Sites

The study sites are located throughout the CRE between Lees Ferry and Diamond Creek (Figure 1). Distances along the Colorado River in Grand Canyon are traditionally measured in river miles, with river mile 0 beginning at Lees Ferry, Arizona. We use the GCMRC mileage system to identify river mileage (Table 1; Breedlove and Meitz, 2002). Table 1 lists which side of the river (left or right as viewed downstream) the camp is located, informal camp names, and the location within either a critical or non-critical reach. This study did not evaluate any campsites above Lees Ferry in the Glen Canyon reach or below Diamond Creek.

The study sites were selected to coincide with a subset of the long-term study sites used by the sand bar monitoring program at Northern Arizona University to monitor changes in sand bar area and volume (Beus et al., 1992; Kaplinski et al., 1995; Kaplinski et al., 1998; Hazel et al., 1999; Hazel et al., 2001; Hazel et al., 2002). These sites were originally selected on the basis of: 1) distribution throughout the geomorphic reaches identified by Schmidt and Graf (1990); 2) they be of sufficient size to guarantee persistence through the period of study; 3) geomorphic diversity within and between sites (separation and reattachment bars, with and without return current channels); 4) availability of historical data; 5) variation in recreational use intensity and vegetation cover (Beus et al., 1992). Because of criteria #5 listed above only a subset of the sand bar monitoring sites could be chosen to monitor campsite areas. These sites, while not chosen randomly, have proven to be representative of system-wide changes to high elevation (above 20,000 ft^3 /s) sand volume and area (Schmidt et al., 2004). Therefore, it is reasonable to assume that changes to campsite areas at these sites are also representative of changes to campsite area, but not carrying capacity.

The study began with 31 study sites. Six sites were added in 2002 for a total of 37 sites. Only the original 31 sites, which have been measured consecutively since 1998, were used to summarize the campsite areas; while all sites were used to calculate average percent change between years. Twelve of these sites are located in Marble Canyon between the Paria River and the Little Colorado River confluence, and nineteen are located in Grand Canyon below the Little Colorado confluence.

Kearsley and Warren (1993) defined critical and non-critical camping reaches, based on the number of sites in the reaches and visitor use patterns. There are eighteen sites located within critical reaches and nineteen in non-critical reaches.

Results

Our results show that the total camp area above the 25,000 ft^3/s stage elevation significantly decreased during the study period (Figure 4). The total campsite area changes were derived by summing all of the campsite area measurements in a particular reach. Between 1998 and 2003, the total campsite area decreased by 55%. The average decrease was 15% between each survey (Table 2). However, the sum of campsite area can bias the dataset towards larger campsites, which may tend to dominate the trend. However, the average percent change calculated for each individual site agrees well with the percent change derived from the sum of campsite area and indicates that the total campsite area is a valid metric to summarize the dataset (Table # 1 and 2).

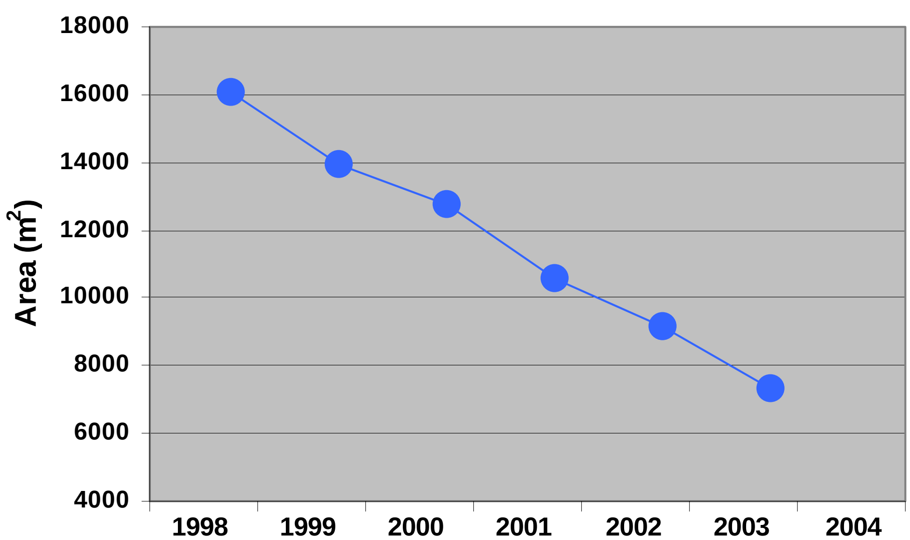


Figure 4. Total camp area above the 25,000 ft^3/s stage elevation.

Table 2. Total campsite area (m^2) above 25,000 ft^3/s stage elevation for different reaches.

Year	Total	Marble Canyon	Grand Canyon	Critical	Non-Critical
1998	16079	6950	9129	5325	10754
1999	13898	6417	7481	5151	8747
2000	12713	4912	7801	5525	7188
2001	10556	3848	6708	4364	6192
2002	9148	3568	5580	3839	5309
2003	7287	2984	4303	3336	3951

Longitudinal changes were examined by comparing the total campsite area above and below the Little Colorado River (LCR) confluence (Figure 5). We use the term Marble Canyon for sites above the LCR and Grand Canyon for sites below. Campsite areas in Marble Canyon and Grand Canyon decreased at a similar rate and show an overall loss of 57% and 53%, respectively. There was a longitudinal difference in the response to the powerplant capacity flows conducted as part of the LSSF. Camp area in Grand Canyon increased slightly by 4% following the high flows of the LSSF, while campsites in Marble Canyon decreased by 24%. Area increases in Grand Canyon camps are possibly related to greater deposition downstream of the Little Colorado River where the sediment supply is assumed to be greater.

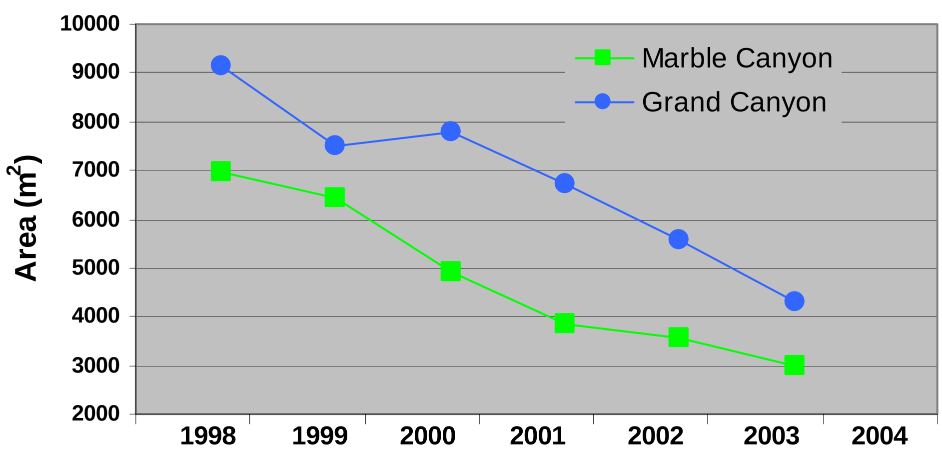


Figure 5. Total camp area above the 25,000 ft^3/s stage elevation in Marble and Grand Canyon.

The pattern of campsite area change was different in critical and non-critical reaches (Figure 6). Total campsite area within critical reaches decreased by 37% during the study period; an average decrease of 8% per year. In non-critical reaches the change was greater, with a total percent decrease of 63% and an average decrease per year of 18%. Campsite area in critical reaches increased slightly by 7% following the LSSF, whereas sites in non-critical reaches decreased by 18%. Critical reaches are generally narrower than non-critical reaches and the campsites tend to be smaller and less vegetated, due to the steep bedrock channels that provide little accommodation space for sediment deposition.

Campsite area exists across the entire range of GCD releases (5,000 ft^3/s to 25,000 ft^3/s) and the amount of camp area available is greatly dependent on flow levels. Management objectives specifically identify camp area above the 25,000 ft^3/s stage elevation – the maximum release allowed under the ROD (U.S. Dept. of Interior, 1996). Our surveys measure campsite areas exposed at the time of the visit and allow campsite area changes to be divided between discrete ranges of stage elevation (Figure 7).

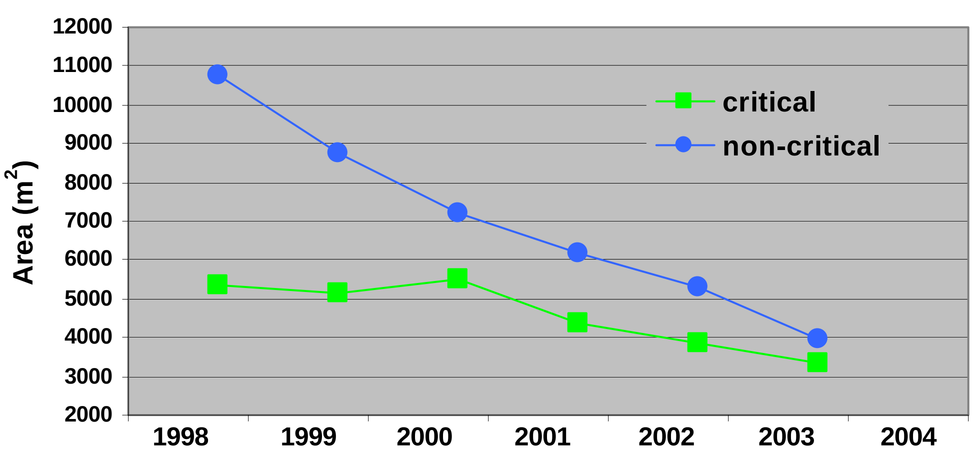


Figure 6. Total camp area above 25,000 ft^3/s stage elevation in critical and non-critical reaches.

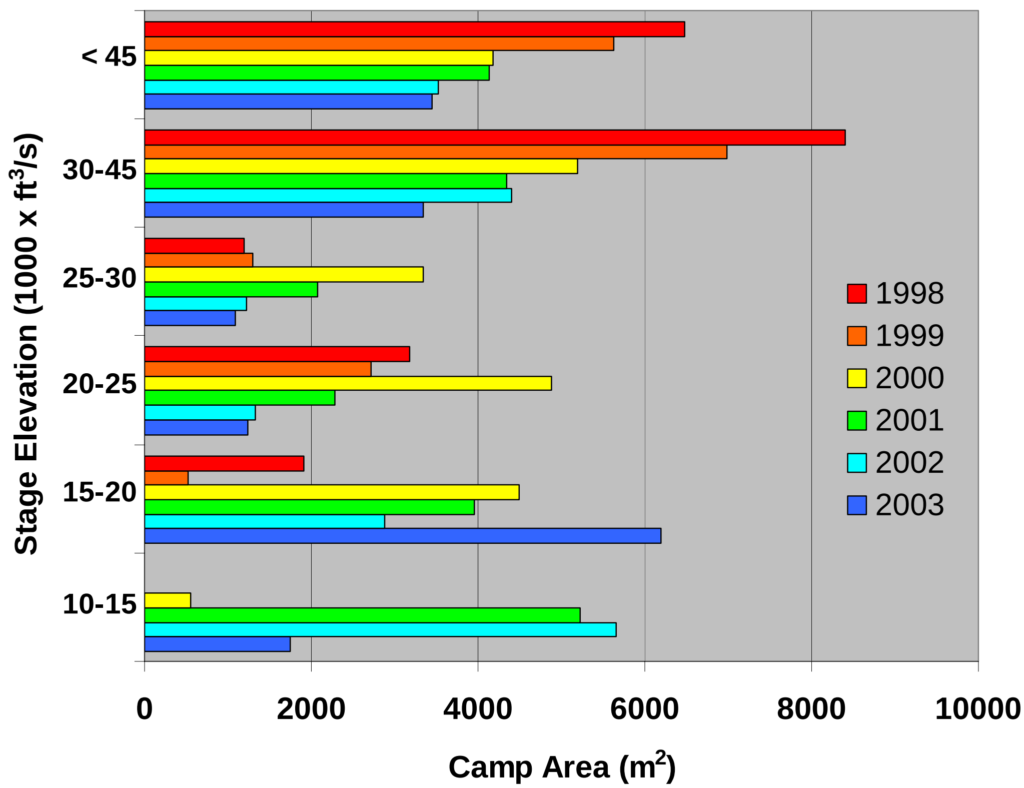


Figure 7. Distribution of total campsite area in six different stage ranges.

High elevation campsite area (above 25,000 ft^3/s) progressively decreased during the study period, with the exception of the short-term increase within the 25,000 to 30,000 ft^3/s range following the LSSF. Subsequent surveys show that this slight increase in campsite area decreased to levels equivalent to those measured in 1998 within two years.

Camp area at lower elevations has increased due to deposition from the high flow events associated with the 2000 LSSF, the high fluctuating flow experiments from January to March 2003, and medium to high volume (10,000 ft^3/s to 25,000 ft^3/s) summer dam operations. In fact, the amount of campsite area available at lower elevations is now greater than that available at higher elevations (Figure 8). Because this area lies within the zone of flow fluctuation, these increases may not persist. Lower elevations of sand bars are more susceptible to bank erosion than sand at higher elevations (Hazel et al., 1999). The lower sand bar elevations are also inundated during

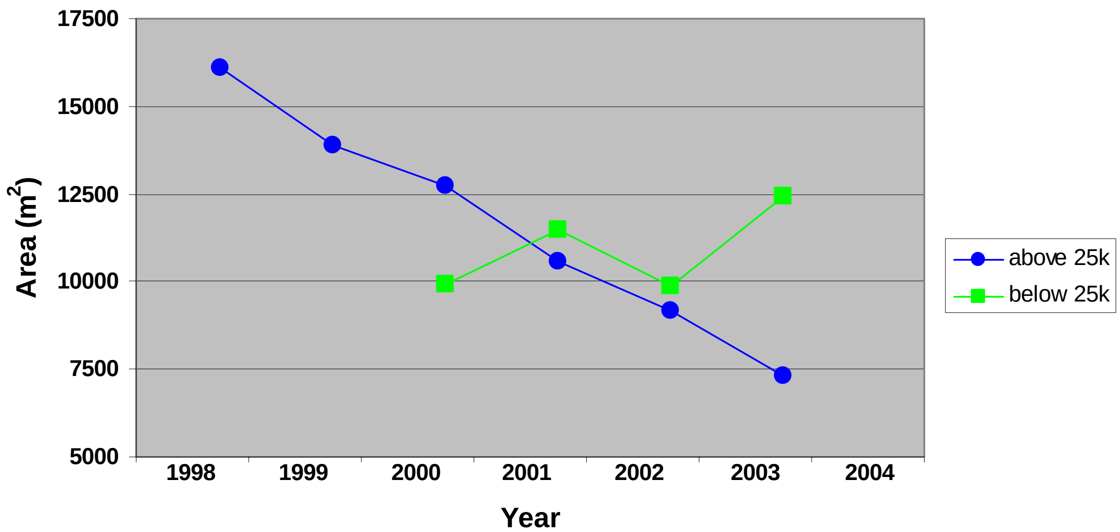


Figure 8. Total campsite area above and below the 25,000 ft^3/s stage elevation.

peak commercial rafting season and are not available for camping. An option available to the GCDAMP for consideration is to lower flows during the commercial rafting season to increase the amount of campsite area available to rafting parties.

Discussion

In order to construct a longer-term view of changes to campsites in Grand Canyon, we compiled the percent change between surveys from the campsite inventories conducted by Brian and Thomas (1984), Kearsley et al. (1994), Kearsley and Quartoroli (1997) and combined them with the results from our study. Figure 9 shows the results of the compilation and describes the history of changes to Grand Canyon campsites from 1973 to 2003. The only two periods of increases in either the number of camps or the size of camps occurred following the high flows of 1983-1984 and the 1996 controlled flood, when flows were greater than power plant capacity. During years between flood events, sand bar erosion, vegetation growth, surface water runoff, and eolian processes combine to decrease the number and size of campsites.

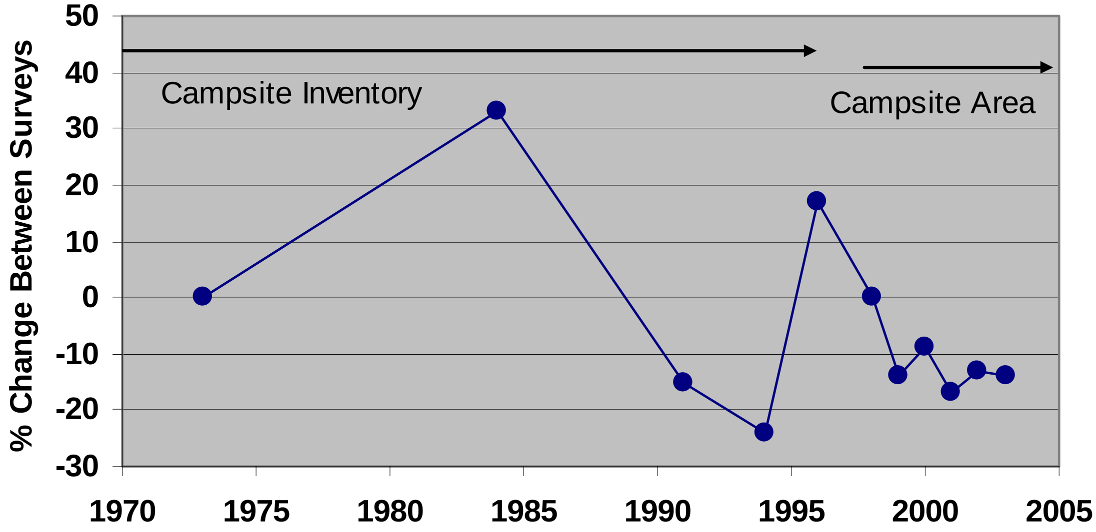


Figure 9. Percent change between campsite surveys combining the campsite inventories conducted by Brian and Thomas (1984), Kearsley et al. (1994), Kearsley and Quartoroli (1997) with the results from this study.

Campsite area and sand bar volume both decreased during the study period. Sand bar volume, derived from detailed topographic surveys, has been monitored at the study sites since 1990 (Hazel et al., 2002). However, campsite area has decreased faster than the actual volume, or size of the sand bar (Figure 10). This indicates that other factors contribute to the loss of high elevation campsite area. These factors include vegetation growth, surface water runoff, eolian processes, and human impact. Although not quantitatively addressed in this study, visual observations indicate that, excluding sand bar erosion, vegetation growth contributes most significantly to the loss of high elevation campsite area. Unfortunately, a comparison of campsite area change and vegetation colonization during the study period is not possible due to the unsuitability of current vegetation monitoring protocols for detecting vegetation change at individual campsites (Mike Kearsley, NAU Biologist, personal communication, 2004). An analysis of past aerial photography could perhaps provide important information to answer this question. Surface runoff events that significantly decreased campsite area were observed at only three sites during the six years of monitoring. Human impacts were minimal, except for locations where vegetation pruning and/or removal actually increased or maintained campsite areas. Eolian reworking of sand bars was not a significant factor due to the amount of vegetation along the higher elevation sand bar areas.

Future campsite monitoring may benefit from recently tested remote sensing technologies. The methods used in this study sample a limited number of campsites and requires on-site visitation for one to several hours. Thus the number of sites that can be surveyed is limited to approximately thirty to forty sites on one river trip. There is also an inherent bias that exists in defining camp area using this method. Even while following the criteria of Kearsley and Warren (1993), choosing specific sites on the ground is a somewhat subjective process. Where do you "outline" the campsite area at each site? For example, is an area near the water that was obviously a kitchen location for a previous camping party included in the campsite area polygon even though it exceeds the slope criteria. These types of issues make this monitoring protocol difficult to apply consistently with different personnel and decrease the precision of the measurements.

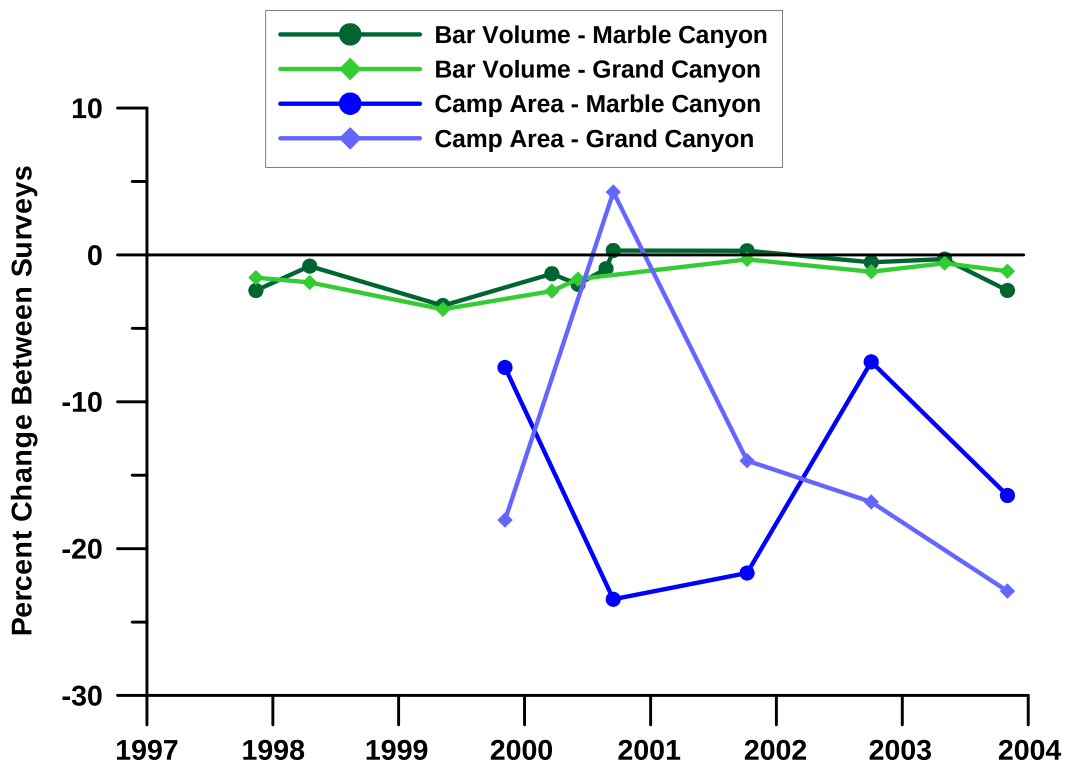


Figure 10. Percent change between surveys of sand bar volume and campsite area in Marble and Grand Canyon.

Given these drawbacks, the strengths of the methods used in this study are that: 1) the accuracy and precision of the measurement technique is the best available; 2) camp area can be assessed at different stage levels; and 3) results of camp area monitoring are directly related to morphological changes. A GIS-based method has been developed that automatically defines camp areas based on visible sand patches and slope criteria (Mike Breedlove, Utah State GIS coordinator, personal communication, 2003). This methodology could potentially sample the entire population of camp sites, provide an estimate of changes in vegetation cover, and the automated process would also eliminate some of the inherent subjectivity of the methods used in this study. However, the camping areas developed using these protocols would require on-site ground truthing to refine the automated polygons and check for mapping errors. In addition, digital orthophoto products need to be available to conduct the mapping. Thus far, the collection, delivery, and quality of these remotely sensed products have been inconsistent.

Research and monitoring of the recreational resources within the CRE suffers from a lack of coordination and integration. This study, for example, directly addressed only one of the five management objectives for the GCDAMP with respect to their stated goal of maintaining or improving the quality of the recreational experience within the CRE. Four of the five management objectives designed to assess whether or not this goal is being achieved are currently not being addressed. In addition, the National Park Service (NPS) has responsibilities to monitor the recreational use within the CRE. In order to include the full suite of management objectives of both the GCDAMP and NPS, a cooperative and integrated program of recreational monitoring and research should be developed. In addition to campsite area monitoring to document the continuing changes in the capacity of the river corridor to accommodate visitor use levels, future research and monitoring should be integrated to include inventories of the total number of campsites, synthesize and collate existing information to construct a comprehensive view of post-dam changes, evaluate the carrying capacity of the river corridor, as well as psychological (experiential) aspects of the resource. This would compliment the detailed area measurements and provide dam managers a more complete assessment of the effects of dam operations on the environmental and social values for which Grand Canyon National Park was formed.

Summary and Conclusions

Campsites within the Colorado River ecosystem exist primarily on sand bars and the size and capacity of camping area is directly related to the areal extent of sand bars and the amount of vegetation colonizing the sand bars (Kearsley et al., 1994). In six years, more than half of the available campsite area at the study sites has been lost. Our results show that camping area above the 25,000 ft^3/s stage elevation has decreased by 55% from 1998 to 2003. The average rate of change was 15% per year. The decrease in high elevation campsite area has occurred in Marble Canyon and Grand Canyon (above and below the Little Colorado River) as well as within critical and non-critical reaches. Only lower elevation campsite areas have increased since 2000 and the total campsite area below the 25,000 ft^3/s stage elevation now exceeds the area available at higher elevations. The rate of high elevation campsite area decrease exceeds that of the decrease in sand bar volume. This indicates that other factors, primarily vegetation growth, contribute to the loss of high elevation campsite area. Unfortunately, a comparison of campsite area change and vegetation colonization during the study period is not possible due to changes in the vegetation monitoring protocols (Mike Kearsley, NAU Biologist, personal communication, 2004).

These monitoring results show that operations from Glen Canyon Dam are not meeting the goals of the GCDAMP with respect to the recreational resources of the CRE. Goal 9 of the GCDAMP is to "maintain or improve the quality of recreational experiences for users of the CRE" (GCDAMP strategic plan, 2001). Towards this goal, the GCDAMP has developed management objectives to assess whether they are achieving the goal. Specific management objectives pertaining to Goal 9 and addressed directly and indirectly by this study include:

> *9.1 –Maintain or improve the quality and range of recreational opportunities in Glen and Grand Canyons within the capacity of the Colorado River ecosystem to absorb visitor impacts consistent with the NPS and tribal river corridor Management Plans.*
>
> *9.3 – Increase the size, quality, and distribution of camping beaches in critical and non-critical reaches in the mainstem within the capacity of the Colorado*

River ecosystem to visitor impacts consistent with NPS and tribal river corridor management plans.

9.4 – Maintain or enhance the wilderness experience in the Colorado River Ecosystem in consideration of existing management plans.

The significant decrease in the size of campsite area in both critical and non-critical reaches during the study period indicates that management objective 9.3 is not being met. While this study does not explicitly link changes in campsite area to the recreational/wilderness experience in Grand Canyon, the significant decrease in campsite area indicates that other management objectives are possibly not being met. For example, a significant decrease in campsite area may indicate a decrease in the range and quantity of recreational opportunities. Also, because existing campsites are smaller and thus more crowded, the quality of campsites is not being maintained or improved. The decrease in campsite area leads to more crowding and less choice for camps, which negatively affect the wilderness experience (Hendee et al., 1990). However, these conclusions are tenuous and more research and monitoring are needed on the psychological aspects of the recreational experience in order to adequately evaluate efforts to meet these aspects of the GCDAMP goals.

The continued existence of sand bars suitable for camping in this system depends on high flows to redeposit sediment lost through the natural processes of erosion and to scour or remove vegetation. Therefore, the availability of campsite area is closely linked with the frequency of flood events from GCD. Unless vegetation is physically removed, high flow events are the only mechanism by which sand bars used as campsites above the 25,000 ft^3/s stage elevation can be built and maintained – provided that enough sediment is available for deposition.

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Appendix 1: Campsite Area Tables

Upper Hot Na Na - 16.6 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/10/1998	367	0	367		0	0	31	336	0
10/4/1999	362.3	0	362.3		0	0	72.3	290	0
10/15/2000	396.3	1	395.3	0	0	1	278.3	117	0
10/6/2001	68	0	68	0	0	0	12	56	0
9/21/2002	79	2	77	0	0	2	33	44	0
9/21/2003	95.5	7	88.5	0	0	7	55	33.5	0

Lower Hot Na Na – 16.6 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/10/1998	281	164	117		0	164	40	0	77
10/4/1999	253.3	120.3	133		0	120.3	28	25	80
10/15/2000	529	349	180	48	195	106	25	133	22
10/6/2001	344	268	76	39	129	100	8	0	68
9/21/2002	153	88	65	10	10	68	5	0	60
9/21/2003	144	68	76	0	7	61	0	0	76

22 Mile – 22.1 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/11/1998	786	720	66		668	52	10	47	9
10/4/1999	579	536	43		110	426	4	24	15
10/16/2000	451	299	152	80	65	154	152	0	0
10/6/2001	666	520	147	386	41	93	147	0	0
9/21/2002	455	349	106	315	0	34	106	0	0
9/21/2003	608	534	74	470	43	21	74	0	0

Harry McDonald – 23.5 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
9/21/2002	631	627	4	0	207	420	4	0	0
9/21/2003	487	487	0	0	205	282	0	0	0

Silver Grotto - 29.5 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
9/21/2002	613	430	183	168	89	173	109	74	0
9/21/2003	612	435	177	253	51	131	87	90	0

Fence Fault Springs - 30.7 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/11/1998	740	443	297		417	26	4	256	37
10/5/1999	547	195	352		190	5	15	306	31
10/16/2000	915	816	99	280	144	392	0	80	19
10/6/2001	1428.2	1354.6	73.6	1130	101.7	122.9	0.6	50.6	22.4
9/21/2002	1011	976	35	729	207	40	0	25	10
9/21/2003	1484	1456	28	843	613	0	0	22	6

South Canyon – 31.9 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/11/1998	642	0	642		0	0	0	80	562
10/5/1999	675	0	675		0	0	0	88	587
10/16/2000	618	0	618	0	0	0	0	48	570
10/7/2001	572	0	572	0	0	0	0	53	519
9/22/2002	315	0	315	0	0	0	0	3	312
9/22/2003	487	0	487	0	0	0	0	22	465

Nautoloid – 35.0 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/11/1998	677	213	464		36	177	40	99	325
10/5/1999	668	126	542		47	79	18	214	310
10/17/2000	719	221	498	0	140	81	4	174	320
10/7/2001	553	83	470	7	19	57	19	185	266
9/23/2002	472	30	442	0	0	30	0	197	245
9/22/2003	547	101	446	71	18	12	21	201	224

Buck Farm – 41.2 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
9/23/2002	844	316	528	112	113	91	35	130	363
9/23/2003	797	314	483	99	142	73	73	15	395

Anasazi Bridge – 43.4 Mile River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/12/1998	1105	0	1105		0	0	55	774	276
10/5/1999	1014	0	1014		0	0	62	752	200
10/17/2000	1268	335	933	5	248	82	30	754	149
10/7/2001	548	22	526	0	22	0	37	358	131
9/24/2002	505	0	505	0	0	0	33	355	117
9/23/2003	221	95	126	85	10	0	27	55	44

Eminence – 44.5 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/12/1998	781	182	599		0	182	0	263	336
10/6/1999	754	128	626		0	128	0	240	386
10/17/2000	988	454	534	26	320	108	2	231	301
10/8/2001	954	501	453	204	271	26	0	206	247
9/24/2002	741	229	512	226	3	0	0	223	289
9/23/2003	1239	672	567	547	112	13	3	232	332

Willie Taylor – 45.0 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
9/24/2002	819	635	184	562	73	0	0	118	66
9/23/2003	1386	1302	84	721	581	0	0	45	39

Lower Saddle – 47.6 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/12/1998	790	25	765		0	25	183	228	354
10/6/1999	832	25	807		0	25	193	216	398
10/18/2000									
10/8/2001	1104	832	272	570	182	80	75	0	197
9/24/2002	1310	1111	199	1111	0	0	0	0	199
9/24/2003	924	556	368	124	238	194	143	93	132

50 Mile, Dino – 50.1 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/12/1998	784	81	703		6	75	24	407	272
10/6/1999	786	0	786		0	0	32	470	284
10/18/2000	758	80	678	0	0	80	101	309	268
10/8/2001	936	210	726	49	99	62	67	437	222
9/25/2002	916	150	766	29	121	0	1	523	242
9/24/2003	597	125	472	86	39	0	11	294	167

51 Mile – 51.5 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/13/1998	1379	102	1277		0	102	0	1264	13
10/7/1999	658	5	653		0	5	14	639	0
10/18/2000	2114	1562	552		1093	469	102	450	0
10/9/2001	2623	2353	270	407	1508	438	106	164	0
9/25/2002	616	196	420	39	157	0	0	420	0
9/25/2003	567	346	221	319	0	27	29	192	0

Kwagunt Marsh – 55.9 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/13/1998	548	0	548		0	0	6	479	63
10/7/1999	424	0	424		0	0	1	298	125
10/18/2000	273	0	273		0	0	0	232	41
10/9/2001	195	0	195	0	0	0	0	167	28
9/25/2002	126	0	126	0	0	0	3	107	16
9/25/2003	30	0	30	0	0	0	1	29	0

Crash Canyon – 62.9 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/14/1998	180	0	180		0	0	0	169	11
10/8/1999	172	0	172		0	0	3	154	15
10/19/2000	228	43	185		0	43	44	128	13
10/9/2000	134	52	82	14	37	1	4	69	9
9/27/2002	72	26	46	23	3	0	19	17	10
9/27/2003	123	97	26	29	65	3	1	15	10

Grapevine – 81.7 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/15/1998	1166	0	1166		0	0	97	1053	16
10/8/1999	1145	17	1128		0	17	105	1008	15
10/20/2000	1352	216	1136		1	215	274	841	21
10/11/2001	1125	28	1097	0	0	28	170	909	18
9/28/2002	887	35	852	0	0	35	114	733	5
9/28/2003	617	86	531	19	44	23	17	514	0

Clear Creek – 84.6 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/20/2000	456	359	97	245	114	0	0	60	37
9/28/2002	327	298	29	107	191	0	0	0	29
9/28/2003	354	335	19	171	164	0	0	0	19

Upper Cremation – 87.7 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/15/1998	200	0	200		0	0	37	140	23
10/8/1999	204	0	204		0	0	76	111	17
10/20/2000	169	0	169		0	0	34	114	21
10/12/2001	117	0	117	0	0	0	15	96	6
9/29/2002	286	111	175	0	94	17	36	113	26
9/28/2003	243	96	147	0	73	23	24	109	14

Lower Cremation – 87.7 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/15/1998	315	0	315		0	0	15	106	194
10/8/1999	193	0	193		0	0	6	43	144
10/20/2000	321	85	236		85	0	51	59	126
10/12/2001	167	22	145	0	22	0	6	42	97
9/29/2002	213	79	134	2	77	0	12	31	91
9/28/2003	146	54	92	34	20	0	3	17	72

91 Mile, Above Trinity – 91.7 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/16/1998	286	0	286		0	0	0	12	274
10/9/1999	286	0	286		0	0	0	29	257
10/21/2000	301	0	301		0	0	32	32	237
10/12/2001	307	0	307	0	0	0	0	58	249
9/29/2002	209	0	209	0	0	0	0	2	207
9/28/2003	337	66	271	26	40	0	0	52	219

Granite – 93.8 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/16/1998	204	0	204		0	0	82	111	11
10/9/1999	162	0	162		0	0	68	82	12
10/21/2000	580	228	352		79	149	274	62	16
10/12/2001	232	22	210	0	0	22	137	59	14
9/29/2002	459	236	223	16	187	33	151	60	12
9/28/2003	413	270	143	0	258	12	91	42	10

104 Mile – 104.4 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/17/1998	133	0	133		0	0	1	95	37
10/9/1999	98	0	98		0	0	3	70	25
10/22/2000	187	52	135		24	28	44	70	21
10/13/2001	183	25	158	0	0	25	41	107	10
9/30/2002	220	82	138	6	46	30	31	98	9
9/29/2003	101	20	81	8	12	0	0	72	9

119 Mile – 119.4 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/18/1998	457	140	317		1	139	34	112	171
10/10/1999	443	143	300		0	143	22	89	189
10/22/2000	1809	1178	631		400	778	391	70	170
10/13/2001	591	263	328	178	37	48	149	37	142
10/1/2001	820	643	177	436	207	0	1	39	137
10/1/2003	1206	1032	174	339	693	0	0	38	136

122 Mile – 122.8 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/18/1998	795	323	472		37	286	57	410	5
10/10/1999	478	22	456		0	22	155	301	0
10/22/2000	1157	868	289		624	244	20	269	0
10/14/2001	1517	1295	222	626	580	89	4	218	0
10/1/2002	1701	1428	273	1129	273	26	62	211	0
10/1/2003	2229	1856	373	960	786	110	100	273	0

Forster – 123.2 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/18/1998	673	297	376		0	297	0	110	266
10/10/1999	448	46	402		0	46	15	84	303
10/22/2000	295	0	295		0	0	96	86	113
10/14/2000	467	243	224	227	16	0	51	92	81
10/1/2002	441	283	158	0	263	20	11	69	78
10/1/2003	662	621	41	31	551	39	10	25	6

Football Field, Middle Beach – 137.7 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/19/1998	1391	764	627		466	298	12	82	533
10/11/1999	1034	461	573		0	461	10	94	469
10/23/2000	1631	845	786		0	845	289	69	428
10/15/2001	1869	1184	685	791	28	365	209	76	400
10/2/2002	2095	1257	838	812	104	341	194	230	414
10/2/2003	2744	2101	643	1127	649	325	115	111	417

Fishtail – 139.6 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/19/1998	323	0	323		0	0	0	106	217
10/11/1999	286	0	286		0	0	0	90	196
10/24/2000	371	192	179		134	58	0	72	107
10/15/2001	213	152	61	0	110	42	0	36	25
10/2/2002	78	0	78	0	0	0	0	50	28
10/2/2003	107	0	107	0	0	0	0	68	39

145 Mile, Above Olo – 145.9 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/19/1998	340	222	118		147	75	0	60	58
10/12/1999	339	225	114		96	129	3	57	54
10/24/2000	423	134	289		0	134	238	18	33
10/16/2001	316	138	178	33	37	68	136	15	27
10/2/2002	343	191	152	3	84	104	112	19	21
10/3/2003	328	207	121	19	100	88	86	20	15

Lower National – 167.1 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/3/2002	504	303	201	65	118	120	74	127	0
10/3/2003	477	315	162	56	106	153	61	101	0

183 Mile, Old River Channel – 183.3 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/21/1998	423	277	146		35	242	0	0	146
10/13/1999	495	359	136		0	359	0	0	136
10/25/2000	686	507	179		222	285	59	0	120
10/17/2001	356	213	143	204	0	9	39	0	104
10/5/2002	415	330	85	318	11	1	33	1	51
10/4/2003	380	315	65	156	159	0	0	0	65

183 Mile – 183.3 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/21/1998	923	532	391		51	481	162	229	0
10/13/1999	226	112	114		82	30	6	108	0
10/25/2000	337	138	199		0	138	130	69	0
10/17/2001	307	115	192	3	56	56	150	42	0
10/5/2002	334	158	176	39	3	116	126	50	0
10/4/2003	375	225	150	0	111	114	106	44	0

194 Mile – 194.6 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/22/1998	1124	0	1124		0	0	2	569	553
10/14/1999	817	0	817		0	0	21	396	400
10/26/2000	889	113	776		35	78	108	322	346
10/17/2001	596	0	596	0	0	0	1	325	270
10/5/2002	723	0	723	0	0	0	0	338	385
10/3/2003	511	0	511	0	0	0	0	249	262

202 Mile – 202.3 Mile, River Left

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/22/1998	1322	582	740		40	542	213	114	413
10/14/1999	1410	695	715		0	695	293	164	258
10/26/2000	1040	514	526		325	189	265	82	179
10/17/2001	1516	771	745	0	233	538	352	151	242
10/6/2002	1707	1275	432	345	513	417	101	133	198
10/4/2003	1044	661	383	0	367	294	14	93	276

Pumpkin Springs – 213.3 Mile, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/23/1998	432	21	411		0	21	70	130	211
10/14/1999	249	33	216		0	33	54	71	91
10/27/2000	769	641	128	111	355	175	79	15	34
10/18/2001	858	780	78	352	428	0	51	9	18
10/6/2002	649	598	51	72	514	12	34	11	6
10/5/2003	738	722	16	93	579	50	13	3	0

220 Mile, Middle Camp – 220.1, River Right

DATE	Total	below 25	above 25	10-15	15-20	20-25	25-30	30-45	above 45
10/23/1998	1600	0	1600		0	0	23	563	1014
10/14/1999	1109	0	1109		0	0	14	469	626
10/27/2000	1065	55	1010		0	55	220	281	509
10/18/2001	1161	21	1140	0	0	21	92	326	722
10/6/2002	660	0	660	0	0	0	7	296	357
10/6/2003	481	53	428	28	15	10	62	138	228